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The spectrum of P *Cygni*[1] ($\alpha = 20^h\ 14^m.1$) resembles that of a nova, in having bright and dark lines apparently side by side, the emission line lying toward the red. The star is in fact a nova, having appeared in the year 1600. The light curve is that of a typical nova, except that the fluctuations were separated by years instead of days, and the fact that the final magnitude is the fifth instead of the twelfth or fifteenth. There are bright lines accompanied by absorption in all parts of the spectrum, from the ultra violet to beyond Hα. This remarkable spectrum continues year after year without appreciable change.

Descriptions of nearly all the stars mentioned in this paper can be found in Harvard College Observatory *Annals*, Vol. 28.

There is an interesting general question in regard to these stars which the future may answer. Are they an offshoot from the tree of stellar evolution? Or are they in the line of regular progression, but few in number because the time of passage through this condition is comparatively short; or because most of the stars have passed this stage in the process of development and there is a paucity of recruits?

MOUNT HAMILTON, CAL., June, 1912.

THE CLUSTER TYPE OF STELLAR VARIATION.

BY C. C. KIESS.

The first discovery of light variation in a star cluster was made in 1889, when Professor E. C. PICKERING noticed a change in brightness of a star near the center of the cluster N. G. C. 5272. A year later Mr. D. E. PACKER reported the discovery of two variables in the outskirts of the cluster Messier 5—a discovery shortly afterward corroborated by Dr. COMMON. But the chief credit for the detection of variables in clusters goes to Professor S. I. BAILEY of the Harvard College Observatory, who, in the course of his duties at the Arequipa station, found that many of the *globular* clusters contain large numbers of variables. Thus, his first examination of photographs of the clusters M3 and M5 led to the discovery of 87 variables in the first cluster and 46 in the second, these numbers being subsequently increased to 132 and 85, respectively.

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[1] *Astrophysical Journal,* **10**, p. 319; *id,* **35**, p. 286; *Lick Observatory Bulletin,* No. 201.

Only a few of the large number of clusters that are scattered throughout the sky have been observed to contain variables; and these few—23 in number[1]—are not equally rich in the number of variables they possess. The ratios expressing the relation between the number of stars whose light varies to the number whose light is constant range from one to seven in the case of M3, to one to 1,050 in the case of the double cluster N. G. C. 869-884. For M5 the ratio is one to 11, and for ω *Centauri* it is one to 24. For the 23 clusters listed the number of variables that each possesses is roughly proportional to the degree of condensation of the cluster; although one notable exception is the great cluster in *Hercules,* in which only two variables have been found. In addition to the clusters, certain nebulæ and the Magellanic Clouds have been observed to contain variable stars, the number of variables observed in the latter being 1,777.

More surprising than the fact that variable stars are present in clusters, was the fact that in the great majority of instances the variation is of a new type. For example, the cluster ω *Centauri* was found to have 37 variables of this new type, which for convenience BAILEY temporarily designated Subclass *a*. In the same cluster are many other variables of the types of which δ *Cephei* and ζ *Geminorum* are the exemplars. But, to use BAILEY'S own words, "in other clusters, however, Subclass *a* appears to be the prevailing type, so much so that the variable stars of this subclass may perhaps be regarded as the typical cluster variables."[2] Accordingly, the name "cluster variables" has been given permanently to stars of this type of variation, which, although of short period, have several characteristics that distinguish them from variables of the *Cepheid-Geminid* type. First of all, their periods range in duration from $0^d.4$ to $0^d.7$, whereas the duration of light change of the ordinary short-period variables is from $0^d.2$ to $44^d.6$, the mean for 98 *Cepheid-Geminid* stars being $9^d.2$. Secondly, the change in light of variables of the cluster type is not continuous, as is the case with *Cepheid-Geminid* stars, but at minimum there is a prolonged halt lasting on the average one-third of the period. This particular feature led HARTWIG to give the name *Antalgol* to stars of the cluster type—a name, which as a descriptive term is more applicable to stars like SS *Cygni* and U *Geminorum* than to cluster variables. The rise from minimum to maximum in stars of the cluster type is very rapid, seldom requiring more than one-fifth of the period; while, on the other hand, for the usual short-period variables the time is from one-third to one-half the period. Again, a distinguishing feature of variables in clusters is that they are all faint, the mean maximum being of the thirteenth magnitude, very few stars differing from this norm by amounts greater than 0.2 magnitude. No such uniformity exists among the ordinary short-period variables. On the other hand, cluster variables resemble *Cepheid-Geminid* variables in that their average range in brightness is approximately one magnitude. In Figure 1 are given

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[1] *Harvard College Observatory Circular,* No. 33.

[2] *Annals of Harvard College Observatory,* Vol. 38, p. 233.

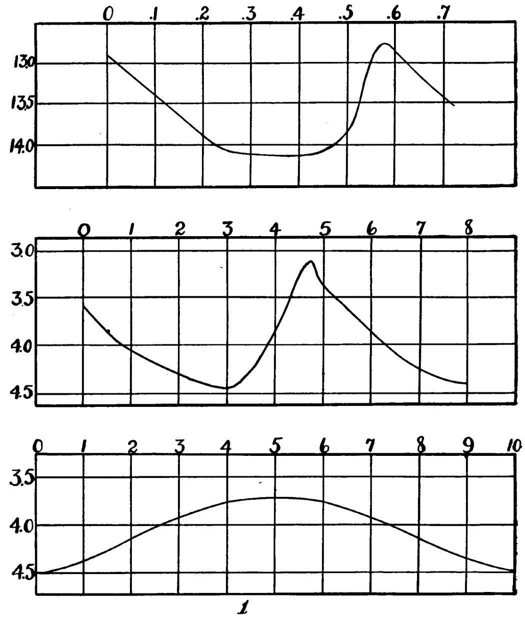

FIG. I.

1. No. 51 ω *Centauri.* 2. δ *Cephei.* 3. ζ *Geminorum.*

three light curves, one of a typical cluster variable, No. 51 ω *Centauri*; the other two of δ *Cephei* and ζ *Geminorum*, prototypes of the *Cepheid-Geminid* group. The curves illustrate the points of resemblance and dissimilarity which have been pointed out for the two groups of variables. The variables in the Magellanic Clouds possess light curves resembling those of cluster variables, but they differ from the typical cluster variables in that their periods range from one to 127 days.

A small number of isolated stars not situated in or near clusters have been found to possess short-period variation of the cluster type. In almost every respect these stars resemble their prototypes in clusters: their periods average about half a day; their variation in brightness averages one magnitude; the minimum phase occupies approximately one-third of the entire period; and the rise from minimum to maximum is very rapid. However, although these stars are faint, there is no such uniformity in their maxima as is the case with variables in clusters. In the following table is given a list of the isolated cluster variables known to date. The headings of the columns are all self-explanatory, except, perhaps, the last. The quantity I/D is the ratio of the duration of increase in brightness to the duration of decrease. The comparison of this ratio for the three divisions of short-period variation is interesting: for the *Geminid* stars it is 1.00; for the typical *Cepheid* stars taken from the Third Catalogue of CHANDLER it is 0.34; and for the stars in clusters it is 0.15. However, for the sixteen isolated cluster variables tabulated below the individual values of the ratio differ widely from the result given above.

TABLE.

Name	1855 α	1855 δ	Epoch J.D. 241	Period	Max.	Min.	I/D
SW *Andromedæ* ..	0^{h} 16^{m}	+28° 36′	8132.805	0^{d}.44185	9.2	10.0	0.31
RZ *Camelopardalis*	6 19	+67 7	9064.2167	0. 48038	11.0	13.0	0.14
SU *Draconis*	11 30	+68 8	8086.2182	0 .66042	8.9	9.6	0.43
SW *Draconis*	12 11	+70 19	8086.2962	0 .56965	8.3	10.4	0.28
ST *Virginis*	14 20	— 0 15	8121.4146	0 .41139	10.3	11.4	0.25
RS *Bootis*	14 27	+32 23	8115.626	0 .37733	9.2	10.2	0.21
RW *Draconis*	16 33	+58 8	7407.2792	0 .44294	9.9	11.0	0.50
ST *Ophiuchi*	17 27	— 0 58	8159.661	0 .45036	10.9	12.4	0.21
S *Aræ*[1]..........	17 50	—49 25	8854.2201	0 .45189	9.3	10.6	0.11

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[1] For the Equinox of 1875.

Name	1855 α	1855 δ	Epoch J.D. 241	Period	Max.	Min.	I/D
Y *Lyræ*	18 33	+43 50	5020.2745	0 .50269	11.0	13.0	0.17
RZ *Lyræ*	18 38	+32 39	8450.233	0 .51128	9.9	10.3	0.28
RT *Scuti*	18 42	—10 33	7728.98	0 .49564	9.1	9.7	...
RR *Lyræ*	19 21	+42 30	8919.448	0 .56682	6.9	7.7	0.24
XZ *Cygni*	19 30	+56 5	7201.2542	0 .46659	8.7	9.3	0.50
UY *Cygni*	20 50	+29 53	5346.3933	0 .56071	9.5	10.4	0.16
RV *Capricorni* ...	20 53	—15 48	7436.87	0 .4476	9.2	10.7	0.35

Up to the present time no satisfactory theory has been advanced to explain the cluster type of variation. Opinion seems to be divided as to whether or not cluster variables constitute a separate and distinct class, or are only an extreme type of the ordinary short-period variation. HERTZSPRUNG, an advocate of the theory that cluster variables are a new class of stellar variation, bases his belief upon considerations deduced from the theory of probabilities.[1] Thus, considering that the frequency with which a period of given magnitude occurs may be regarded as a function of the period itself, we have—

$$\frac{n}{m} = y = f\,(P) = \frac{1}{\sqrt{\pi}}\, e^{-P^2}$$

whence,

$$\log \frac{1}{\sqrt{\pi}\, y} = P^2$$

where the ratio n/m denotes the probability of the occurrence of a period of magnitude P, n times out of m instances. Applying this equation to the 16 stars tabulated above and to 98 short-period variables (listed on pages 282-285 of the *V. J. S. der Astronomischen Gesellschaft,* 46 Jahrgang, 1911), we get the curves given in Figure 2. Inclusion of the many variables in clusters with the 16 from which curve (a) was drawn, would only steepen the curve still more. (If drawn to the horizontal scale of (b), curve (a) would be entirely included between the two lines (c). The vertical scales of the curves are the same.) If among the ordinary short-period variables we include a number of stars whose periods are 0.6 of a day and less,

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[1] *Publikationen des Astrophysikalischen Observatoriums zu Potsdam;* Nr. 65, pp. 52-53, footnote.

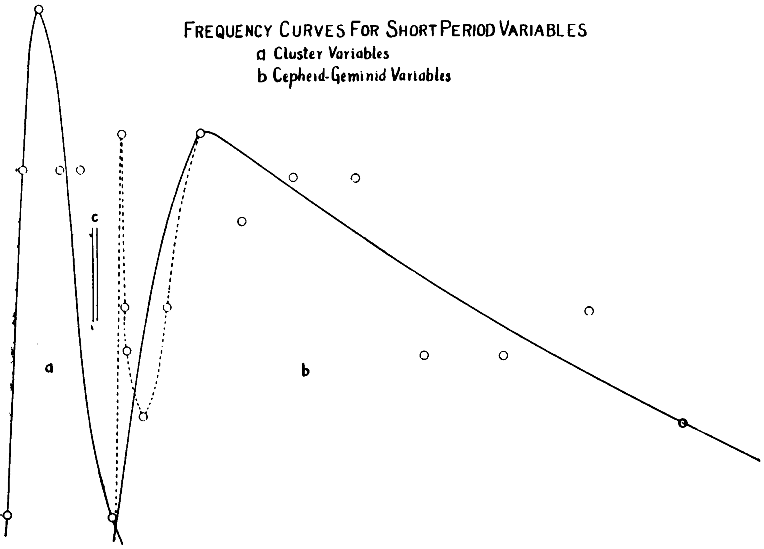

FIG. 2.

we get the curve represented by the dotted line in (b). The dotted curve greatly resembles curve (a) and would seem to lend weight to Professor CAMPBELL'S statement that, "it is probable that some of these extremely short-period variables may later be assigned to the cluster variables."[1] It is to be noted, however, that an increase in the number of cluster variables whose periods range between $0^d.55$ and $0^d.65$ would make less steep the right-hand branch of curve (a), and increase its resemblance to curve (b).

If, on the other hand, cluster variables are but extreme types of ordinary short-period variation, then satisfactory theories of short-period variation should afford an explanation of cluster variation. To sum up briefly, the eleven *Cepheid-Geminid* variables which have been studied spectroscopically have been found to be binaries with orbital periods synchronous with their light periods. Furthermore, their greatest brilliancy occurs when their velocity of approach to the solar system is greatest. The mean eccentricity of their orbits is 0.31, and the mean *a sin i*, the projection of the semi-major axis on the line of sight, is 1,500,000^{km}. Hence we may infer that all short-period variables are close binary systems of high eccentricity. The three theories of greatest weight which have been advanced to explain short-period variation are: the tidal theory, the resisting-medium theory, and the variation-in-absorption theory.[1] According to the first theory, the periodic light variation is a direct consequence of the variation in the enormous tides produced in the atmosphere of the bright component by the larger and perhaps darker component of the binary system. In his earlier paper on the cluster variable S *Aræ,* ROBERTS endorses this theory and explains the cause of variation in the following words: "An eccentricity of 0·5 would yield sufficient periodic change in the mutual tidal force of each component of S *Aræ* to cause an alteration in brightness of at least one magnitude; while even a retardation of a few minutes of the maximum tidal effect after periastron passage would produce the rapid rise to maximum brightness that is so markedly a feature of the variation of S *Aræ* as well as of all stars of this type."[2] WILLIAMS also, in his discussion of the light curves of Y *Lyræ* and UY *Cygni,* advocates the opinion that the so-called cluster variables are only extreme types of *Cepheid* variation, and he points out that there is no sharp line of demarcation between the two classes, but rather there are light curves of almost every shape between the two extremes.[3]

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[1] *Lick Observatory Bulletin*, No. 181, p. 51.

However, certain phenomena observed to be characteristic of short-period variation find no explanation in the hypothesis of tidal action, and characteristics required by the hypothesis have not been observed. Consequently, greater weight is accorded to the two remaining theories which have been proposed to explain the *Cepheid-Geminid* type of variation. As its name implies, the resisting-medium theory[4] seeks to account for the periodic light variation, which the bright member of a binary system undergoes, by assuming that its advancing surface is heated up by the impact of the meteoric material in the resisting medium in which the system is enveloped. This theory accounts for many of the peculiarities of short-period variation, but it too demands the existence of characteristics which have not been observed.

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[1] A short account of these and other theories is given in *Popular Astronomy,* Vol. XIX, pp. 408-414.

[2] *Monthly Notices R. A. S.,* Vol. 61, p. 164.

[3] *Monthly Notices R. A. S.,* Vol. 63, pp. 310-311.

[4] *Lick Observatory Bulletin,* No. 62.

The third theory, which may be termed the variation-in-absorption theory,[1] accounts for the changing intensity of the light of the variable by supposing that as it swings about its darker primary its atmosphere is brushed back by the extended corona of the primary. Thus, on the advancing side of the bright member of the system, the atmosphere is not so deep, and consequently the absorption not so great, as on the following side. This theory, proposed by DUNCAN, accounts for the observed phenomena of short-period variation, and has no serious objections against it. Accordingly it is made the basis of a new theory recently advanced by ROBERTS to explain the cluster type of variation.

According to the new theory,[2] the light curve of a cluster variable is a composite of an eclipse curve and an ordinary short-period variable curve. In other words, cluster variables are short-period variables so situated with respect to the line of sight that periodically the phenomenon of eclipse occurs. The brighter component of the binary system is a variable whose light-change is due to change in the absorbing powers of its atmosphere. Maximum brilliancy occurs at quadrature, but as the following side of the star gradually comes into view the light wanes until it is cut off in eclipse by the passing of the variable behind its larger and less brilliant primary. The minimum phase of the light curve, which extends over nearly a third of the period, represents the constant and steady light which we receive from the primary, while the eclipse of the secondary is in progress. On the basis of this theory ROBERTS has computed the magnitudes of S *Aræ,* and their agreement with the observed values is very close. Hence, it would seem that the theory has much to commend it.

But before we can give full accord to any theory of cluster variation we must have definite knowledge of certain facts.

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[1] *Lick Observatory Bulletin,* No. 151.

[2] *Astrophysical Journal,* Vol. XXXIII, p. 197 ff.

We must know whether the variable star belongs to a binary system, and if so, whether its period of orbital revolution coincides with its period of light-change. We must know also whether its velocity curve is a reflection of its light curve, or whether it is a modified sine curve, as is the case with eclipsing variables. Furthermore, we must know whether maximum light coincides with maximum velocity of approach and whether there is any change in the nature of the light which we receive from the system. On all these points we must have definite knowledge before we can decide in favor of one or the other of the above-mentioned theories, or must seek an altogether new explanation. We await the evidence which a star bright enough for spectroscopic study and analysis can give us.

THE SPECTRUM OF *NOVA GEMINORUM* NO. 2.

By W. H. Wright.

The spectrum of *Nova Geminorum* No. 2 was observed during March, April, and May. Unfortunately the weather was cloudy for several days after the announcement of the discovery of the star, so that it was impossible to observe it before March 16th. Between that date and May 27th forty-one spectrograms were secured.

The observations were made with the single prism spectrograph attached to the 36-inch refractor, and with the 2-prism quartz spectrograph used with the Crossley reflector. Taken together, they cover the region included between 3250A and 6850A. During the period which they cover, many remarkable changes occurred in the spectrum. In this brief note it will be impossible to more than touch upon some of these, a fuller discussion being reserved for a forthcoming paper.

The characteristic features of the spectrum as photographed on March 16th, three days after the announcement of the discovery of the star, were continuous spectrum crossed by the usual bright and dark bands and by some dark bands not seen in previous novæ. The hydrogen series was represented by bright bands accompanied on their more refrangible edges by broad dark lines. On March 20th these dark companion lines